

REMARKS ABOUT UNIFORM BOUNDEDNESS OF RATIONAL POINTS OVER FUNCTION FIELDS

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1. Introduction and preliminaries. A curve X of genus at least 2 defined over a function field L has only finitely many L rational points, unless it is isotrivial. Similarly, a curve of genus at least 2 defined over a number field F has a finite set of F -rational points. These well known facts are celebrated theorems of Y.Manin and G.Faltings, originally conjectured by L.J.Mordell and S.Lang.

We study here questions of uniformity for the cardinality of such sets of rational points, in the function field case. For number fields, there are a number of open conjectures, such as the following (Uniform Mordell Conjecture for number fields): *Fix $g \geq 2$ and a number field F ; there exists a number $B_g(F)$ such that any curve of genus g defined over F has at most $B_g(F)$ rational points over F .* Interest in such problems was revived after it was proved in [CHM] that the Conjecture above is a consequence of a famous, open, Conjecture (usually attributed to S.Lang and E.Bombieri) on the non-density of rational points in varieties of general type (see also [A], [AV] and [Pa]).

In this paper we investigate similar issues for curves over function fields. Some partial results were obtained in [Mi] and in [C] where the existence of uniform bounds for the sets of rational points is established. Such bounds depend on suitable numerical invariants of the function field, on the genus g of the curves and on the degree of the locus of bad reduction (that is, the locus of singular fibers).

We shall also study here the strictly related “uniform Shafarevich problem”; a famous Theorem of A.N.Parshin and S.Ju.Arakelov ([A] and [P]) states that *if B is a smooth complex curve and $S \subset B$ a finite subset, then there exists only a finite number of non-isotrivial families of smooth curves of fixed genus $g \geq 2$ over $B - S$.* Parshin first proved it under the assumption that $S = \emptyset$; Arakelov generalized it a few years later. In [P] Parshin shows also that the Theorem above implies finiteness of rational points for non-isotrivial curves of genus at least 2, providing the above mentioned link between the Shafarevich problem and the Mordell problem. Recall that his argument, known as the “Parshin trick”, is valid for both number fields and function fields.

A first uniform version of the Theorem of Parshin and Arakelov above is obtained in [C]. We here generalize it by a stronger uniform result valid for families of curves over bases of any dimension. This is done in Section 2, where we obtain bounds (for the sets of curves with fixed degeneracy locus as well as for the sets of rational points) that only depend on the degree of a polarization on the base variety, and on the degree of the locus of bad reduction. A stronger result can be obtained for curves having good reduction in codimension 1 (Theorem 3). In Section 3 we will consider families with maximal variation of moduli, using the geometry of the moduli space of curves to approach our problems.

We work over \mathbb{C} , by V we shall denote a smooth, irreducible, projective variety over \mathbb{C} , whose field of rational functions will be $L := \mathbb{C}(V)$. Special interest will be given to varieties of dimension 1, for which we shall use the following notation: B is a smooth

irreducible curve and K its field of rational functions. We fix integers $q \geq 0$, $g \geq 2$ and $s \geq 0$ throughout. The genus of B will be denoted by q .

We shall consider smooth curves of genus g over the function field L (or K), which can also be viewed as families of curves over V , such that there is a non-empty open subset of V over which the fibers are all smooth. We shall always assume that such a family (or curve) is not isotrivial, i.e. the smooth fibers are not all isomorphic.

To be more precise, we introduce the following sets: let B be a fixed curve and let $S \subset B$ be a finite set of points.

Definition. $F_g(B, S)$ shall denote the set of equivalence classes of non-isotrivial families $f : X \rightarrow B$ such that X is a smooth relatively minimal surface and the fiber X_b over every $b \notin S$ is a smooth curve of genus g . Two such families $f_i : X_i \rightarrow B$ for $i = 1, 2$ are equivalent if there is a commutative diagram

$$\begin{array}{ccc} X_1 & \xrightarrow{\alpha'} & X_2 \\ f_1 \downarrow & & \downarrow f_2 \\ B & \xrightarrow{\alpha} & B \end{array}$$

where the two horizontal arrows are birational maps.

Using a different terminology, $F_g(B, S)$ is the set of K -isomorphism classes of non-isotrivial curves of genus g over K , having good reduction outside of S . The Theorem of Parshin and Arakelov says that $F_g(B, S)$ is finite. Theorem 3.1 of [C] states that there exists a number $P(g, q, s)$ such that $|F_g(B, S)| \leq P(g, q, s)$ for every curve B of genus q and for every subset S having at most s points. We show here (in the end of Section 2) that this result is sharp in the sense that such a bound must depend on s .

We are interested in function fields of higher transcendence degree. We can generalize the definition of $F_g(B, S)$ as follows. Let $T \subset V$ be a closed subscheme.

Definition. $F_g(V, T)$ shall be the set of equivalence classes of non-isotrivial families of smooth curves of genus g over $V - T$ (the equivalence relation is the same as above, with B replaced by $V - T$).

By the existence and unicity of minimal models for smooth surfaces, this definition coincides with the previous one if $\dim V = 1$. It follows from the results in [C] (3.4) that $F_g(V, T)$ is finite. Our best result on $F_g(V, T)$ is Theorem 1.

If X is a curve defined over a field L , we shall denote by $X(L)$ the set of its L -rational points. If X has genus at least 2 and it is not isotrivial, the Theorem of Manin says that $X(L)$ is finite. Consider now the Uniformity Conjecture for rational points over function fields, which can be stated as its arithmetic analogue: *Let L be a function field over \mathbb{C} and let $g \geq 2$ be an integer. There exists a number $N_g(L)$ such that for every non-isotrivial curve X of genus g defined over L we have $|X(L)| \leq N_g(L)$.* For results relating it to the Lang Conjectures about the distributions of rational points on varieties of general type, see the work of D. Abramovich and J.F. Voloch [AV].

Such a Conjecture remains open; our results in that direction are Theorems 2 and 3 and Proposition 4.

A final piece of notation. M_g denotes the moduli variety of smooth curves of genus g and \overline{M}_g its compactification via Deligne-Mumford stable curves. They are both integral, normal varieties of dimension $3g - 3$. A universal curve exists only on a proper open subset of M_g (and of \overline{M}_g). In particular, a morphism $\phi : Z \rightarrow M_g$ does not necessarily come from a family of curves over Z . If this is the case, that is, if there exists a family of smooth curves $X \rightarrow Z$ such that for every $z \in Z$, $\phi(z)$ is the isomorphism class of the fiber of X over z , we shall say that ϕ is a *moduli map*.

2. Uniformity results for function fields of high transcendence degree. We start by a uniform generalization for the Theorem of Parshin and Arakelov. The result below is a strengthening of 3.4 and 3.5 in [C], in fact the bound H here is independent of the dimension of V and of r . Such an improvement is obtained by a small technical modification of the methods in [C].

Notice that statement below remains true if V is replaced by an integral, possibly singular, projective variety. The proof is essentially the same.

Theorem 1. *Let $g \geq 2$, $d \geq 1$, $s \geq 0$ be fixed integers. There exists a number $H(g, d, s)$ such that for any smooth, irreducible variety $V \subset \mathbb{P}^r$ of degree d , for any closed subscheme $T \subset V$ of degree s , we have $|F_g(V, T)| \leq H(g, d, s)$. Moreover, if T has codimension at least 2 in V , then the bound H does not depend on s .*

Proof. Step 1. Slicing V into curves of bounded genus. Considering one-dimensional hyperplane sections of V , we see that V can be covered by smooth curves of degree d passing through any of its points; it is a well known fact that the genus of a curve of degree d in projective space is at most equal to $\binom{d-1}{2}$: just project the curve birationally onto a curve of degree d in \mathbb{P}^2 . Let

$$q = q(d) = \binom{d-1}{2}$$

so that V is covered by curves of geometric genus at most q .

Step 2. Uniform boundedness of moduli maps. By Theorem 3.1 in [C], for any fixed g, q', s' there exists a number $P(g, q', s')$ such that for any smooth curve B of genus q' , for any subset $S \subset B$ of at most s' points, we have that $|F_g(B, S)| \leq P(g, q', s')$.

Define

$$H' = \max_{q' \leq q, s' \leq s} P(g, q', s')$$

so that H' only depends on g, d, s ; let $U = V - T$.

We claim that U has at most H' moduli maps to M_g , that is, we claim that there exist at most H' non-constant, (regular) morphisms $\phi : U \rightarrow M_g$ such that there exists a (not necessarily unique, see below) family of smooth curves over U whose moduli map is ϕ . By contradiction, let $n > H'$ and let us assume that there exist ϕ_1, \dots, ϕ_n distinct such moduli maps $\phi_i : U \rightarrow M_g$. Let $X_i \rightarrow U$ be a non-isotrivial family of smooth curves corresponding to ϕ_i (since ϕ_i is a moduli map, such a family exists, but it is not necessarily unique). Let $U' \subset U$ be the non-empty open subset where $\phi_i(u) \neq \phi_j(u)$ for

every $u \in U'$ and for every pair of distinct i, j . Let $p \in U'$ and let $F_i = \phi_i^{-1}\phi_i(p)$; since ϕ_i is not constant, its fiber F_i through p is a proper closed subset of U' , therefore there exists a curve $B \subset V$ of genus at $q' \leq q$ such that $p \in B$ and such that $B \not\subset F_i$ for every $i = 1, \dots, n$; thus the restriction of X_i to B is not isotrivial for every i . Let $S = (B \cap T)_{red}$. Let $Y_i \rightarrow B$ be the smooth relatively minimal completion over B of the restriction of X_i to B . By construction, Y_1, \dots, Y_n , are different elements of $F_g(B, S)$, which is a contradiction, since $F_g(B, S)$ has at most $P(g, q', s') \leq H' < n$ elements. This proves the claim. Notice that if T has codimension at least 2 in V we can always choose our B so that it does not intersect T at all, and hence S can be taken to be the empty set and H' does not depend on s .

Conclusion. Given a moduli map $\phi : U \rightarrow M_g$ the set of families that have ϕ as moduli map is uniformly bounded, in fact it is bounded above by a function of g only (see [C] Lemma 3.3), hence we are done. \square

A similar argument yields the following uniformity statement for rational points, stronger than 4.3 and 4.4 in [C]:

Theorem 2. *Let $g \geq 2$, $d \geq 1$ $s \geq 0$ be fixed integers. There exists a number $N(g, d, s)$ such that for any smooth, irreducible variety $V \subset \mathbb{P}^r$ of degree d , for any closed subscheme $T \subset V$ of degree s and for any non-isotrivial curve X of genus g defined over $L = \mathbb{C}(V)$ and having good reduction outside of T , we have $|X(L)| \leq N(g, d, s)$. Moreover, if T has codimension at least 2 in V , then the bound N does not depend on s .*

Proof. Step 1. Repeat word by word Step 1 in the proof of the previous Theorem.

Step 2. Theorem 4.2 in [C] says that if g, q', s' are fixed non-negative integers, there exists a number $M(g, q', s')$ such that for any curve B of genus q' , for any subset S of at most s' points in B , for any curve $X_B \in F_g(B, S)$ we have that

$$|X_B(\mathbb{C}(B))| \leq M(g, q', s').$$

Arguing as in the proof of 4.4 of [C] one gets that defining

$$N(g, d, s) := \max_{q' \leq q, s' \leq s} M(g, q', s').$$

will suffice to our statemnt. \square

To conclude, we show that for curves having good reduction in codimension 1, stronger finiteness results hold. Let L be a function field over \mathbb{C} and let V be a smooth, projective, complex variety of positive dimension such that $L = \mathbb{C}(V)$.

Definition. Let $C_g^2(L)$ be the set of L -isomorphism classes of non-isotrivial curves of genus g over L having good reduction in codimension 1.

In other words, $C_g^2(L)$ is the set of equivalence classes of non-isotrivial families $X \rightarrow V$ of curves of genus g over V such that there exists a closed subscheme $T \subset V$ of codimension at least 2 with the property that X_v is smooth for every $v \notin T$.

Theorem 3.

- a) $C_g^2(L)$ is finite
- b) There exists a number $N_g^2(L)$ such that for every curve $X \in C_g^2(L)$ we have $|X(L)| \leq N_g^2(L)$.

Proof. We shall use moduli maps. Denote by $M_g^2(L)$ the set of equivalence classes of non-constant rational maps $\phi : V \longrightarrow M_g$ such that there exists an open subset $U^\phi \subset V$ with the following properties:

1. The complement of U^ϕ has codimension at least 2 in V ,
2. ϕ is regular on U^ϕ ,
3. There exists a (non-isotrivial) family of smooth curves of genus g over U^ϕ such that ϕ is its moduli map.
4. Two such maps ϕ and ψ are equivalent iff they coincide on some (non-empty) open subset of V .

There is a natural surjective map of sets:

$$\mu : C_g^2(L) \longrightarrow M_g^2(L)$$

sending a curve over L to its moduli map (it is easy to see that μ is well defined). Now, μ has finite fibers (Lemma 3.3 in [C]) and is surjective by definition. Thus $C_g^2(L)$ is finite if and only if $M_g^2(L)$ is finite.

Part b) is an immediate consequence of part a), by the Theorem of Manin. We will prove our result by showing that $M_g^2(L)$ is finite by induction on $\dim V$. If $\dim V = 1$, the finiteness of $C_g^2(L)$ and of $M_g^2(L)$ is the Theorem of Parshin (the locus of bad reduction being empty in such a case). Let then $\dim V \geq 2$ and suppose that $M_g^2(L)$ is infinite. Notice that $M_g^2(L)$ is dominated by a union of finite sets as follows; if T is a closed subset of V , denote by $M_g(V, T)$ the set of equivalence classes of moduli maps to M_g that are regular on $V - T$, then $M_g(V, T)$ is finite, by Theorem 1 and Lemma 3.3 in [C]. We have a natural, surjective map

$$\bigcup_{\text{codim}_V T \geq 2} M_g(V, T) \longrightarrow M_g^2(L)$$

hence, if $M_g^2(L)$ is infinite, so is the union on the left hand side. Then there exists a countable collection $\{T_n, n \in \mathbb{Z}\}$, with T_n a closed subset of V of codimension at least 2, such that the set

$$M := \bigcup_{n \in \mathbb{Z}} M_g(V, T_n)$$

is infinite. Now, M itself being a countable set, we shall put an ordering on it:

$$M = \{\phi^i, i \in \mathbb{N}\}$$

For every pair of distinct i, j , denote by $U^{i,j}$ the non-empty open subset of V such that $U^{i,j} \subset U^{\phi^i} \cap U^{\phi^j}$ and $\phi^i(u) \neq \phi^j(u)$ for every $u \in U^{i,j}$. The $U^{i,j}$ s form a countable

collection of non-empty open subsets of V , whose intersection I is dense in V . Let $p \in I$ and, for every $i \in \mathbb{N}$, let $F_i = (\phi^i)^{-1}\phi^i(p)$ be the fiber of ϕ^i through p . Since ϕ^i is non-constant (by assumption) F_i is a proper closed subset of V , thus the complement of $\cup_{i \in \mathbb{N}} F_i$ intersects I in a subset J , with J dense in V . Fix a (non-degenerate) projective model of V in some projective space. Then there exists a hyperplane H such that $p \in H$, such that $H \cap J \neq \emptyset$ and such that H does not contain any T_n . Let $W = H \cap V$, we can furthermore choose H so that W is smooth. By construction we have

- (a) $\dim W = \dim V - 1$
- (b) $\dim T_n \cap W = \dim T_n - 1 \leq \dim W - 2$
(since H does not contain any T_n)
- (c) $\forall \phi^i \in M$, the restriction $\phi^i|_W$ is not constant
(since $p \in W$ and $W \cap J \neq \emptyset$)
- (d) $\forall i \neq j$ we have $\phi^i|_W \neq \phi^j|_W$
(since $W \cap I \neq \emptyset$)

hence $\phi^i|_W \in M_g^2(\mathbb{C}(W))$ and the restriction to W gives an inclusion (by (d) above) $M \hookrightarrow M_g^2(\mathbb{C}(W))$. Thus $M_g^2(\mathbb{C}(W))$ is infinite. This is a contradiction with the inductive assumption. \square

See [Md] for an analogue over \mathbb{Q} . Part a) of this result should be compared with the examples of A. Beauville (in [B], section 5) or with the example below. They show that the assumption that the curves have good reduction in codimension 1 is crucial, that is, a) is false without that assumption. On a different vein, compare also with Proposition 6. The example that we are going to describe shows that there is no hope of getting a substantially stronger uniform version of the Shafarevich Conjecture for function fields; in other words, any uniform bound on $|F_g(B, S)|$ must depend on the degree of S .

What happens to the cardinality of $F_g(B, S)$ when s grows while g and q (or even B) stay fixed? The way we defined $F_g(B, S)$, it is an exercise to show that its cardinality is not bounded; but this is just because the families parametrized by $F_g(B, S)$ are not required to have singular fibers over S . The interesting question is about the asymptotics of the cardinality of that subset of $F_g(B, S)$ parametrizing families of curves that have singular fiber over every point of S . We will make this precise now, describing an example suggested by J.DeJong, showing that the set of fibrations with fixed degeneracy locus is not bounded, as the cardinality of the degeneracy locus grows.

Fix $g \geq 2$ and $B = \mathbb{P}^1$, given a subset $S \subset \mathbb{P}^1$ denote by $F(S) \subset F_g(\mathbb{P}^1, S)$ the set of all genus g non-isotrivial fibrations $X \rightarrow \mathbb{P}^1$ such that the fiber X_b is smooth if and only if $b \notin S$.

Let $S = \{a_1, \dots, a_s\}$ be a set of generic points in \mathbb{P}^1 , and let $I \cup J = \{1, 2, \dots, s\}$ be a partition of $\{1, 2, \dots, s\}$ in two disjoint subsets such that $|I| = 5$. Define a non-isotrivial fibration X_I of curves of genus 2 over \mathbb{P}^1 by the affine equation

$$y^2 = (x - t)\prod_{i \in I}(x - a_i)\prod_{j \in J}(t - a_j)$$

with t affine coordinate in \mathbb{P}^1 . For $t \notin S$ (and $t \neq \infty$) we get a smooth curve of genus 2. For $t = a_i$ with $i \in I$, we get a nodal curve and for $t = a_j$, $j \in J$, we get a singular,

non-reduced curve. Thus $X_I \in F(S \cup \infty)$ and by varying the partition $I \cup J$ we get a total of $\binom{s}{5}$ different such fibrations. Hence the cardinality of $F(S)$ goes to infinity, as $|S|$ grows.

One final word about this example.

First, we make two comments: the given family has fibers of genus 2, but of course one can construct the same example for any genus, (just replace the integer 5 by a higher odd number), obtaining families of hyperelliptic curves.

The second comment is about the singular fibers over a_j with $j \in J$, which are not stable curves; their semistable reduction is actually a smooth curve. The remaining 5 fibers over a_i are instead nodal. In other words, the moduli map ϕ_I associated to the family $X_I \longrightarrow \mathbb{P}^1$

$$\phi_I : \mathbb{P}^1 \longrightarrow \overline{M}_2$$

(such that $\phi_I(t)$ is the isomorphism classes of the fiber of X_I over t) intersects the boundary Δ_2 in exactly 5 points, regardless of the cardinality of S .

We ask:

(a) Can one find similar examples whose fibers do not belong to any proper closed subset of M_g ?

(b) Is the same “unboundedness” result true for families of stable curves? In other words, does there exist a similar example all of whose singular fibers are nodal?

3. Uniformity for “truly varying” curves. This section contains results that are independent of the degeneracy locus. Given a family $X \longrightarrow V$ of generically smooth curves of genus g over V , we get a natural rational map $\phi : V \longrightarrow M_g$ (regular on a non-empty open subset of V). The dimension of the image of ϕ is called the *variation of moduli* of the family; we shall say that the family has *maximal variation of moduli* if

$$\dim \text{Im} \phi = \min\{\dim V, 3g - 3\}.$$

We shall say that a curve over $L = \mathbb{C}(V)$ has maximal variation of moduli if a corresponding family of curves over V does.

Thus the condition of having maximal variation of moduli can be interpreted as saying that the family (or the curve) is *truly varying* and can be viewed as a generalization of the non-isotriviality condition. Obviously, if the base field has transcendence-degree 1, a curve is non-isotrivial if and only if it has maximal variation of moduli.

Definition. Let L be a function field, we define $C_g(L)$ to be the set of L -isomorphism classes of curves of genus g defined over L and having maximal variation of moduli.

Proposition 4. *Let $g \geq 24$ and let L be a function field of transcendence degree $3g - 3$. Then*

- a) $C_g(L)$ is finite
- b) There exists a number $N(L, g)$ such that for every curve X of genus g defined over L and having maximal variation of moduli, we have $|X(L)| \leq N(L, g)$

c) There exists a function $P_g(n, m)$ such that for every V of general type, we have $|C_g(L)| \leq P_g(\dim V, K_V^{\dim V})$.

Proof. The assumption $g \geq 24$ implies that \overline{M}_g is of general type (for this famous result of J.Harris and D.Mumford we refer to [HMu] and to 6F in [HM]).

Denote by $R(V, \overline{M}_g)$ the set of dominant, rational maps from V to \overline{M}_g . A Theorem of Kobayashi-Ochiai [KO] implies that, \overline{M}_g being of general type, $R(V, \overline{M}_g)$ is finite. Notice now that there is a natural bijection between $C_g(L)$ and $R(V, \overline{M}_g)$: to a truly varying curve X of genus g over L we can associate its moduli map $\phi_X \in R(V, \overline{M}_g)$. The fact that such a correspondence is bijective follows from the existence of the universal curve over an open subset of \overline{M}_g . Thus $C_g(L)$ is finite.

By the Theorem of Manin, any curve in $C_g(L)$ has a finite set of L -rational points, thus part b) follows immediately from a)

Part c) is proved like part a); we can in this case apply a strengthening of the Theorem of Kobayashi-Ochiai provided by T. Bandman and D. Markushevich. From [BM] we obtain that, V and \overline{M}_g being of general type and \overline{M}_g having canonical singularities (Theorem 1 in [HMu]), there exists a function of g , of $\dim V$ and of $K_V^{\dim V}$ bounding the cardinality of $R(V, \overline{M}_g)$ and hence that of $C_g(L)$. \square

Let $u : \mathcal{C}_g \longrightarrow M_g^\circ$ be the universal curve over the moduli space of automorphism free smooth curves of genus g , so that the fiber of u over the point corresponding to the curve X is X itself.

It is a well known fact (see [HM] 2D) that u has no rational sections, thus, \mathcal{C}_g has no rational point over the function field of M_g . In fact much more is known: the Picard group of \mathcal{C}_g is generated over the Picard group of M_g by the relative dualizing sheaf ω_u ; therefore a multisection of u must have degree over M_g° equal to a multiple of $2g - 2$.

We apply this to obtain that if V is a variety of dimension $3g - 3$ and X is a curve of genus g over L having maximal variation of moduli, then a necessary condition for X to have a rational point over L is that its moduli map have degree equal to a multiple of $2g - 2$. This follows easily by looking at the commutative diagram

$$\begin{array}{ccc} X & \xrightarrow{\gamma} & \mathcal{C}_g \\ f \downarrow \uparrow \sigma & & \downarrow u \\ V & \xrightarrow{\phi_X} & M_g \end{array}$$

where the horizontal arrows are rational maps and σ is the rational section corresponding to a rational point of X over L . Let $\tau = \gamma \circ \sigma : V \longrightarrow \mathcal{C}_g$ and let $\rho : \text{Im} \tau \longrightarrow M_g$; by what we said, $\deg \rho = n(2g - 2)$ for some integer n . We finally obtain

$$\deg \phi_X = \deg \tau \cdot \deg \rho = m(2g - 2).$$

Where by $\deg \phi_X$ we mean the degree of the restriction of ϕ_X to the non-empty open subset of V where ϕ_X is a regular and finite map. Let us call such a number $\deg \phi_X$ the *modular degree* of a family $X \longrightarrow V$; this definition is general, provided that $X \longrightarrow V$ has maximal variation of moduli and that $\dim V \leq 3g - 3$. We just proved the following

Lemma 5. *Let V be a variety of dimension $3g - 3$ with function field L and let X be a smooth curve of genus g over L having maximal variation of moduli. Then either $X(L) = \emptyset$ or the modular degree of X is a multiple of $2g - 2$.*

The following well known conjecture is open:

Geometric Lang Conjecture. *Let W be a variety of general type defined over \mathbb{C} . Then there exists a proper closed subvariety Z_W of W containing all positive dimensional subvarieties of W that are not of general type.*

In particular, according to such a Conjecture, all curves in W having genus at most 1 are contained in Z_W .

Consider now \overline{M}_g , and let $Z_g \subset \overline{M}_g$ be defined as the closure of the union of all integral curves in \overline{M}_g having geometric genus at most equal to 1. Since \overline{M}_g is of general type if $g \geq 24$, the above conjecture would imply that Z_g is a proper, closed subset of \overline{M}_g for all $g \geq 24$.

As a consequence, we get the following

Lemma 6. *Let $g \geq 24$ and B be a curve of genus q . The Geometric Lang Conjecture implies that if $X \rightarrow B$ is a non-isotrivial family of curves of genus g , passing through the general point of M_g , then the modular degree of X is at most $q - 1$.*

Proof. As we mentioned above, the union of all curves in \overline{M}_g of genus at most 1 is contained in a proper closed subset Z_g of \overline{M}_g . The condition that the given family of curves goes through the general point of \overline{M}_g , combined with the Geometric Lang Conjecture, implies that $\text{Im}\phi_X \not\subset Z_g$. Thus the geometric genus of $\text{Im}\phi_X$ is at least 2. By the Riemann-Hurwitz formula, the degree d of a dominant map of a curve B of genus q onto a curve C of geometric genus $p \geq 2$ is at most equal to $q - 1$, in fact the formula gives

$$d = \frac{2q - 2 - r}{2p - 2} \leq \frac{q - 1}{p - 1} \leq q - 1$$

since $r \geq 0$ (being the degree of the ramification divisor) and $p \geq 2$ by assumption. \square

Aknowledgments I am grateful to Olivier Debarre and to Johann DeJong for useful conversations and to Felipe Voloch for indicating relevant references. Special thanks to Dan Abramovich for pointing out a serious mistake in a previous version of this paper.

References

- [A] D.Abramovich. *On the number of stably integral points on an elliptic curve.* Inventiones Math. 128, 481-494 (1997).
- [AV] D.Abramovich, J.F.Voloch: *Lang's conjectures, fibered powers, and uniformity.* New York J. Math. 2 20-34 (1996)
- [A] S.Ju.Arakelov: *Families of algebraic curves with fixed degeneracies.* Izv. Akad. Nauk. SSSR Ser. Mat.35 (1971) no. 6, 1277-1302.

- [BD] T.Bandman, G.Dethloff: *Estimates of the number of rational mappings from a fixed variety to varieties of general type*. Ann. Inst. Fourier (Grenoble) 47 (1997), no. 3, 801-824.
- [BM] T.Bandman, D.Markushevich: *On the number of rational maps between varieties of general type*. J. Math. Sci. Univ. Tokyo 1 (1994), no. 2, 423-433.
- [B] A.Beauville: *Exposé n. 6* in *Séminaire sur les pincesaux des courbes de genre au moins deux*. Astérisque 86 (1981).
- [C] L.Caporaso: *On certain uniformity properties of curves over function fields*. Preprint, AG/9906156, to appear in Compositio Mathematica.
- [CHM] L.Caporaso, J.Harris, B.Mazur: *Uniformity of rational points*. Journal of American Mathematics Society, Vol. 7, N. 3, January 97 p. 1-33.
- [DF] M.De Franchis: *Un teorema sulle involuzioni irrazionali*. Rend.Circ.Mat Palermo 36 (1913), 368.
- [HM] J.Harris, I.Morrison: *Moduli of curves*. Graduate texts in Math. 187 (1998) Springer
- [HMu] J.Harris, D.Mumford: *On the Kodaira dimension of the moduli space of curves*. Inventiones Math. 67 (1982), no. 1, 23-88.
- [KO] S.Kobayashi, T.Ochiai: *Meromorphic mappings into compact complex spaces of general type*. Inventiones Math. 31 pp. 7-16 (1975).
- [Md] M.Martin-Deschamps: *Conjecture de Shafarevich pour les corps de fonctions sur Q* . In Astérisque No. 127, Appendice à l'exposé IX (1985), 256-259.
- [Ma] Y.Manin: *Rational points of algebraic curves over function fields*. Izv. Akad. Nauk. 27 (1963), 1395-1440.
- [Mi] Y.Miyaoka: *Themes and variations on inequalities of Chern classes*. Sgaku 41 (1989), no. 3, 193-207.
- [Pa] P.Pacelli. *Uniform boundedness of rational points*. Duke Math.J. Vol 88, No 1 pp 77-102 (1997).
- [P] A.N.Parshin: *Algebraic curves over function fields*. Izv. Akad. Nauk. SSSR Ser. Mat.32 (1968) no. 5, 1145-1170.
- [S] L.Szpiro: *Exposé n. 3* in *Séminaire sur les pincesaux des courbes de genre au moins deux*. Astérisque 86 (1981).
- [V] E.Viehweg: *Quasi-projective moduli for polarized manifolds*. Ergebnisse der Mathematik (30) Springer.

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(Revised December 2000)